NICKEL
Past and Present

·PAST AND PRESENT

by Robert C. Stanley

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FOREWORD

NICKEL PAST AND PRESENT, a paper by Robert C. Stanley, president of The International Nickel Company of Canada, Limited, was presented at the Second Mining and Metallurgical Congress, held in Canada in 1927 under the auspices of The Canadian Institute of Mining and Metallurgy and published in the Bulletin of the Institute. The paper deals with nickel, a most important factor in Canada's mineral production, since the richness and quantity of her nickel ores have made Canada the world's chief source of supply of the metal.

During the last few years additional information has become available and much progress has been made in the nickel industry.

Permission to publish this amplification of the original paper, with complete revision of the sections on uses and markets, has been granted by the Canadian Institute of Mining and Metallurgy.

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EARLY HISTORY

PROBABLY the first use of nickel by man was in the fashioning of implements, and later swords, from nickel-bearing meteorites, masses of metal that have fallen from time to time at many points on the earth's surface and which consist normally of iron carrying substantial amounts of nickel.

Meteorites were perhaps the first metal known to man. The falling star, sought out with fear overborne by curiosity, was found to be a better stone than the earth-given, truly a boon from the gods. Archæologists tell us there is good evidence that the ancient oriental peoples learned at an early date to make these stones into useful implements.

The invincible blades of the great warriors of old in China, Persia, and in northern Europe, were Heaven-sent, a fable which sounds significant of meteoric iron. Probably some of the ancient swords of Khorassan and of Damascus were of meteoric nickel-bearing iron ([1]).

Fifty centuries were to pass before men learned to isolate nickel and add it to iron to produce the same alloy for much the same purpose.

Meanwhile, man had found another natural alloy of nickel, known first to the Chinese as *paktong* or 'white copper.' It was obtained from complex copper-nickel sulphide ores of Yunnan in southern China. This metal was brought by caravan through India into Bactria, a country north of the Hindu-Kush mountains, in what

([1]) Zimmer, G. F., Jour. Iron & Steel Inst., 1916 (2), p. 306.

is now known as Russian Turkestan. The earliest specimen extant is a Bactrian coin attributed to 235 B.C.

The rough reddish-white metal was also sent in the form of triangular rings to Canton, where zinc ores were added and the whole smelted to a more malleable alloy, also known later as Paktong. This alloy was the forerunner of German- or nickel-silver. Specimens of this alloy, wrought into ornamental candlesticks and boxes, were brought from Canton to Europe by the East India Company in the early days of the China trade. Paktong was highly prized for its beauty as well as its eastern origin in far-away China. By 1760 the unwrought metal was imported into England for domestic manufacture.

While English craftsmen were attempting to rival the delicate Chinese workmanship in the strange new metal, miners in Sweden and in Germany were discarding quantities of its mother ore. At Schneeberg, in Saxony, where from times immemorial silver and copper mines had existed, fresh lodes of ore were laid open, so glittering and full of promise as to cause the greatest excitement. After innumerable trials, and endless labour, instead of a useful metal, ductile, malleable, and indestructible by fire, all that could be obtained from the ore was a worthless metal, brittle and friable under the hammer (1). In disgust, the superstitious miners named the ore *kupfer-nickel*, after 'Old Nick' and his mischievous gnomes, who were supposed to have plagued the miners and bewitched the ores.

After wrestling for five years with a similar ore from Helsingland, Cronstedt in 1751 succeeded in extracting a new element

(1) Bonnin, A., Tutenag and Paktong; Oxford University Press, 1924.

which he named *nickel*. Wherever the news spread the name tenaciously clung to the new element. In all languages its name remains nickel.

Cronstedt's results were challenged by a number of experimenters until, in 1775, after a laborious series of investigations, Bergman confirmed them. Almost thirty years elapsed before Richter produced the first pure nickel. Bearing in mind the difficulties under which work had to be carried out in those days, Richter's description of the properties of nickel in 1804 is a marvel of accuracy ([1]).

It was not until after Cronstedt's discovery and Bergman's work that von Engeström in 1776 discovered nickel in the famous paktong ([1]). For a time, manufacturers had visions of great profits from a domestic paktong. An arms factory at Suhl, near Erfurt in Germany, succeeded in recovering copper-nickel from the slag dump of an old copper works to form a white alloy for gun furniture. The struggle with the obstinate ore went on for fifty years before a satisfactory imitation of paktong was produced.

In 1824, the brothers Henninger, of Berlin, placed the first imitation paktong on the market. About the same time, Geitner of Saxony produced a similar white metal which he named *argentan*. In 1830, one Guiticke brought from Berlin to Sheffield, England, a sample of the synthetic silver-like metal. The generic term for these alloys thereafter became German-silver.

The refining of nickel in England dates from the year of Guiticke's visit. The first efficient substitute for paktong known in England was Merry's *metal blanc*, produced at Birmingham in

([1]) Hadfield, R. A., Alloys of Iron and Nickel; Minutes of the Proceedings of Inst. Civil Eng., 138, 1-167, 1899.

1832 by Henry Merry and Charles Askin, the latter one of the founders of the present firm of Henry Wiggin & Company, Ltd. Many German-silver paktongs were soon flourishing under a variety of trade names, including *electrum,* produced by Messrs. Topping of London, about 1850. As production increased and the composition of the alloy became a matter of common knowledge, less paktong was imported from the East.

The advent of electroplating made an important change in the uses of nickel. One of the first commercial applications of Faraday's great discovery of obtaining electricity from magnetism was in the use of an electroplating machine constructed by Prime & Company, of Birmingham, in 1844. Electroplating had a twofold effect on nickel: one in introducing silver-plated ware with a German-silver base, in competition with the more expensive Sheffield plate; and the other, nickel plating itself. Of the two, silver plating on German-silver was the more important, and the practice then established remains today one of the prominent uses of nickel.

Although Boettger, as early as 1843, discovered that a bright electro-deposit of nickel could be produced using nickel ammonium sulphate, the difficulty of obtaining the metal for anodes in a sufficiently pure state effectively prevented commercial development of nickel plating until about 1870. This use of nickel, although the best known, has at no time been of more than secondary importance. A small quantity of nickel, if spread in gossamer thinness, will make a large display.

During the first fifty years of active work with nickel, German-silver, later known as nickel silver, was almost the only form in which nickel was used commercially. In 1850, the Swiss Government decided to use German-silver as the carrier of real silver in token-money coinage. There was great difficulty in both smelting and rolling the alloy. The coins were too hard to take a good impression, and lacked lustre.

In 1859, a Belgian commission on currency reform effectually assailed the theory, then prevailing, that the intrinsic value of token money must approximate its nominal value. Consequently, after a thorough investigation of various compositions, a seventy-five—twenty-five copper-nickel alloy was recommended on the basis of economy as well as appearance and workability. Belgium adopted this composition in 1860. The United States, which in 1857 had substituted an eighty-eight—twelve copper-nickel composition for the heavy copper penny, adopted a seventy-five—twenty-five composition in 1865. Germany did likewise in 1873, and Switzerland in 1879. Pure nickel coinage did not appear until 1881, largely due to lack of knowledge of the malleability of pure nickel.

The great contribution of Joseph Wharton to the metallurgy of nickel was the first production, in 1865, of malleable pure nickel. Up to that time nickel had been employed only in alloys. Wharton carried out the earliest experiments which were successful in producing nickel in a pure malleable condition, susceptible of being worked under the hammer. In 1873, he sent to the Vienna Exposition samples of nickel forgings, and at the Exhibition in Philadelphia, in 1876, he displayed a remarkable series of objects made of wrought nickel. These were also exhibited in Paris in 1878.

The same year Fleitmann patented the method of obtaining malleability by adding small amounts of magnesium to the melt. He later patented the use of manganese for the same purpose. Nickel so treated was rolled into sheets and drawn into wire. Fleitmann also succeeded in rolling sheet nickel upon iron, and also upon steel plates, much as silver is rolled on copper in making Sheffield plate. These developments led to the manufacture of nickel culinary ware, and here again Fleitmann at Schwerte, Ruhr, was the pioneer in what has become an active and extensive industry.

Until the mining of nickel ores on the island of New Caledonia got well under way, about 1877, ores were sought all over the world —in China, South Africa, and South America. The supply of nickel was so scant that ores containing as little as one per cent. of nickel were profitably worked. The sources of nickel in Europe were at first chiefly the arsenical and silicate ores of the mines in Saxony, where, as already stated, kupfer-nickel had been discovered and named before the isolation of the metal in 1751. By 1873 these mines were sufficiently prosperous to employ 1,200 men in the mines and smelters. Some ores were also obtained in France and Sweden.

In Great Britain, nickel-sulphide ores were mined in Cornwall from 1852 onward, and also in Scotland and in Wales. In the Russian Ural mountains, nickel-serpentine (garnierite) deposits were worked as early as 1866, with a small production at various times. Mines containing similar ores in Italy, Spain and Austria, were actively producing in the 'seventies.

In Norway, mining of pyrrhotite-chalcopyrite ores, similar to those of Sudbury, Canada, began in the 'forties and reached its greatest importance in the period 1870-1877. Norway controlled the nickel market prior to the advent of New Caledonia as a producer.

In the United States, mines were worked in Connecticut, Missouri, and Pennsylvania. The pyrrhotite ores of Litchfield county, Connecticut ([1]), discovered in 1661, were shipped to China about one hundred years later, and in 1818 to England. The ores of Mine La Motte, Missouri ([2]), worked by French explorers as early as 1719, were shipped to nickel refiners in England about 1830-1850. They failed to become a prominent factor, however, due to difficulty in separating nickel from lead. The important mine in the United States was at Lancaster Gap, Pennsylvania ([3]). Nickel ore from this mine was not treated until 1850, although the mine had been worked previously for copper. Refining was first started in Philadelphia, but operations were transferred to Camden, New Jersey, in 1853. Joseph Wharton leased the Camden works in 1863 and purchased them in 1869.

By 1887, the competition of New Caledonian ores had brought all other nickel mining, save that in Norway, to a standstill. Garnier had discovered the New Caledonian deposits in 1865, but their momentous value and extent were not realized until the geological survey reports were published in 1874. During the next fifteen years, New Caledonia was the principal source of nickel for an enormously increasing demand.

The occurrence of nickel ore in Canada was reported as early as 1848. In the Sudbury district, the first authentic discovery was recorded about 1856. At that time the country was a vast wilderness, and it was not until the advent of the railway, twenty-seven years later, that clearing and exploration began. Sudbury was at that time the terminus of the Canadian Pacific Railway, from which point construction was being pushed westward. In the course of this

(1) Blake, W. P., U. S. Geological Survey, 1883, pp. 399-407.
(2) Keyes, C. R., Missouri Geological Survey, 1894, vols. 6, 7, and 9.
(3) Blake, W. P., Trans. Amer. Inst. Min. Eng., 1883, XI: 274-281.

work a cutting was made which passed through an outcrop of copper ore that was later to be the Murray mine. Prospectors after copper immediately flocked into the surrounding country, and a very large number of claims were staked. The rich copper-ore discoveries made on the line of the Canadian Pacific stimulated Samuel J. Ritchie, who had built the Central Ontario Railway, to go to Ottawa in search of tonnage for his railway. He soon became interested in, and purchased the holdings of McAllister, Metcalf, Frood, Creighton, McConnell and later the Evans and Crean Hill properties, which led to the organization in 1885 of the Canadian Copper Company, with Mr. Ritchie as its first President.

When mining operations were begun the owners were still unimpressed by the presence of nickel in the ore. Colonel R. M. Thompson of the Orford Copper Company at Constable Hook, New Jersey, contracted to smelt the ore but he soon found that the copper would not come out. All that could be obtained was a worthless alloy—a repetition of the experience of the German miners a century previous.

While Colonel Thompson was wrestling with the problem of the separation of the nickel and copper, which was subsequently solved by the Orford, and later by the Mond process, Mr. Ritchie had to face the problem of creating a market for his nickel. The World's annual consumption of nickel, in 1889, was four thousand tons, whereas the rich ores of his Canadian mines were ready to turn out twice that amount. The price, which had been $1 a pound or more when the Canadian deposits were first opened up only a few years before, had shrunk to 65c by 1889. (See Chart 2, page 75.) The market was heavily over-stocked. German-silver, electroplating and coinage were practically the only uses for the metal. The future of the Canadian industry depended upon the extension of the market by finding new uses for nickel.

At this juncture Mr. Ritchie recalled an experience some years before in Washington. He had met there John Gamgee, an Englishman, who had interested the Government in the building of a refrigerated hospital ship for treatment of yellow-fever patients in the Gulf ports. Gamgee investigated ammonia refrigerating machines but soon found that cast iron would not hold compressed ammonia gas. He tried all kinds of alloys. Then, going one day through the Smithsonian Institute with Mr. Ritchie, he saw some nickel-iron meteorites and decided to try such an alloy. Mr. Wharton furnished some nickel with which Gamgee produced a very superior nickel-iron alloy which held the gas. Gamgee's ship was never built but he had demonstrated the possibilities of nickel-iron alloys. Of all the possible uses, nickel-iron alloys caught Mr. Ritchie's imagination as the most promising. Faraday had alloyed nickel and iron in 1820. Wolf, Liebig, Fairbairn, and Thurber had called attention to the properties of these alloys. Sir Henry Bessemer in 1858 had tried to produce "meteoric-iron guns." Parkes, of Birmingham, had patented nickel-iron alloys in 1870.

Mr. Ritchie wrote to the famous gun-maker Krupp, at Essen, telling him of the remarkable corrosion-resistant alloy Gamgee had produced, and asking him about the possible use of nickel-iron in gun manufacture. In the reply from Krupp the matter was treated lightly and the belief expressed that there was not a sufficient quantity of nickel in the world to warrant experiments looking to any extended use of the metal. However, nickel-iron alloys were being thoroughly investigated at that time. The appearance of chrome-steel projectiles made in France about 1886, had shown high penetration against wrought iron and compound armour plate, the best protection then known by the leading navies.

Marbeau, of La Société Ferro-Nickel of Paris, had attracted the interest of British armour plate manufacturers by his production of ferro-nickel and nickel steel at the Montataire works in 1885-1887 and James Riley, manager of Tennant & Sons Steel Company of Glasgow, was commissioned to investigate. His results were presented in his now famous paper in 1889, on "Alloys of Nickel and Steel." In the discussion of the paper, J. F. Hall of Sheffield, reported independent work confirming Mr. Riley's results.

Mr. Ritchie brought this report to the attention of the Secretary of the Navy of the United States. Its importance was immediately recognized. Lieutenant B. H. Buckingham, of the United States Navy, and Sir Charles Tupper, of Canada, accompanied Mr. Ritchie abroad to gather further information. They visited a number of the leading steel and ordnance makers in Great Britain and Europe, as well as the principal companies engaged in the production and refining of nickel. They found all very much aware of the importance of nickel, and several who were obviously desirous of gaining control of the new deposits or their output.

As a result of the reports on this investigation, the United States Navy ordered a nickel steel plate and a plain steel plate from Le Creusot works of Schneider and Company in France, and also a plain steel plate such as was then used by the British Navy, from Cammell and Company of Sheffield. At the trial of these plates in 1891, the nickel steel proved decisively superior. The results were immediately of great interest all over the world. The United States Congress appropriated a large sum of money for the purchase of nickel, to be used in making nickel steel armour plate for its navy.

The next ten years witnessed intensive research into the properties and treatment of nickel steels. By 1900, there was available to engineers much sound and useful information, as evidenced by Hadfield's exhaustive paper before the Institute of Civil Engineers, in 1899, on "Alloys of Nickel and Iron."

Soon the exacting requirements made necessary additional studies of steel applications and properties. In detail of knowledge and in care of procedure, these studies added a further important fund of information on the nickel steels. Second to ordnance, and growing simultaneously with it, came bridge building, and then the automotive uses of nickel steel.

This condition continued without a break up to the beginning of the World War in 1914. German-silver, nickel plating, pure nickel and copper-nickel coinage, though consuming large quantities of the metal, had become relatively of less importance than in former years as a result of the increasing demand for nickel for the great navies, and for ordnance, bridge building, and the automobile.

The war created an unparalleled demand for the metal. The Canadian mines extended their resources to the utmost to furnish nickel for the Allies, and every effort was made to speed up production. Industrial uses were neglected in order that ordnance demands might be supplied. Germany commandeered nickel cooking utensils and nickel-bearing coinage. Old German mines were reopened. These, with the added production until 1916 from Norway, were Germany's sources of supply.

The Armistice in 1918 brought to a close a four-year period of high-pressure production. It also brought to a close a longer period of about fifteen years, during which the steadily increasing prosperity of the industry had been based largely upon building great navies and equipping great armies. The effect of the armistice was not fully realized until the completion of war contracts in 1920. The graph of annual nickel production is a mute witness to the heavy deflation of 1919-1921. (See Chart 1, page 75.) The total world production of nickel fell back to what it had been about 1900.

With the close of the war the nickel industry faced the problem of creating new markets. Once before adequate uses for nickel had been developed where there seemed to be none. The conditions at the end of the war were similar to those confronting Mr. Ritchie in 1889. The nickel producers realized that their efforts must again be centred on a well directed, vigorous search for uses of nickel.

RECENT MARKET DEVELOPMENT

THE present industrial era is one of unprecedented engineering activity and technical research,—a legacy in part from the war,—which may be characterized as the period of market development and stabilization in the industries of peace. Certainly, urgent military-engineering requirements—airplanes, submarines, gas-warfare equipment, etc.—stimulated to a high pitch all the engineering thought and activity of the nations. The war period achievements of research and invention spread to all industries and the momentum of this activity has not subsided since the war. It has been effectively applied to the problems in reconstruction of industry arising out of the disturbing depression that immediately followed the war.

With reconstruction came rapid development of improved machinery and construction of all kinds. There was a demand for improved and special materials of construction. There was also a new receptiveness on the part of the engineer, almost an eagerness, to give careful and constructive consideration to all such new materials, an attitude in contrast to that of definite conservatism existing before the war.

This is the soil in which the new nickel market grew and flourished. The recovery of nickel consumption probably could not have occurred so rapidly except for this exceptionally favourable atmosphere of engineering interest and liberalism.

Many industrial applications of nickel products have been favoured by this new situation. Some of the more striking examples are: the rapid development of nickel-chromium and nickel-chromium-iron alloys, used as electric, heat and corrosion-resisting materials; the discovery and use of the remarkable magnetic nickel-iron alloys; the development of nickel cast irons; and the increased diversity of uses of the non-ferrous nickel alloys.

Active Interest and Effort of the Nickel Producing Companies

During the life of the present nickel-producing companies, their interest and effort had, up to 1919, largely been directed toward the economic production of the metal in rapidly increasing tonnages. Only once in the past had their effort been exerted effectually in developing the nickel market; namely, during the 'nineties, when the industrial use of nickel steel was established for armour plate and ordnance.

When the market thus created collapsed in 1919-1921, the producers realized that their effort must again be directed to the discovery of new uses for nickel. They saw clearly that the large demand for war purposes was at an end, and that new industrial fields must be found to fill the gap. Since the war, development of a market for nickel has been the dominant activity of the nickel producers.

This activity has taken all of the usual directions, including increased sales effort and advertising, as well as increased attention to quality of products. One feature however which is new, at least within the industry, deserves special mention. This is the creation of new uses, and the extension of those already established, by engineering development and research in the market field. ([1]).

Nickel products are used largely for engineering purposes because they possess certain definite and valuable engineering proper-

(1) The principal nickel producer organized at once a special Department of Development and Research, to carry out this effort.

ties, often highly special in character. The placing in the hands of engineers generally of accurate, detailed information and data on the various nickel products, is an important part of the program. The principal engineering groups and executives are given information on the possibilities of nickel products for use in their designs and constructions. This is done by personal contact, by engineering bulletins, and by special articles in the engineering press.

Another part of this type of activity is the development of new and useful products of nickel through research. Many new products of nickel are possible, as well as industrial fields of usefulness for them. To develop them, the nickel producer must assume the burden of the work. An excellent illustration is the case of nickel in cast iron.

Sir William Fairbairn suggested the improvement of cast iron by the addition of nickel as early as 1858, and Leon Guillet, in 1907, described its essential beneficial effects. Yet no industrial development based upon these experiments took place. No one was interested.

Not until the nickel producers took up this matter, investigated it thoroughly in their laboratories, and demonstrated the value of nickel in practical foundry operations, was there any real industrial use of nickel for this purpose. At present, some fifteen hundred tons of nickel are sold for cast iron yearly, and the use is increasing rapidly.

Influence of the Automotive Industry

Every metal industry has profited by the phenomenal growth during the past twenty years of the automobile industry, and nickel is no exception. There has been a rapidly increasing consumption by this industry of nickel in many forms, principally nickel steels and nickel plating. Nickel has profited indirectly as well from the favourable effect which automobile development has had on engineering activity generally, in stimulating search for and consideration of new materials and in maintaining the present progressive and liberal attitude toward new developments. Without doubt, the automotive engineer has been the most prominent engineering pioneer in industry.

THE PRESENT INDUSTRIAL USES OF NICKEL

THE diversification of the uses of nickel during the post-war period is a remarkable episode in the history of the metal. A brief outline of the growth during recent years will be of interest. It has already been pointed out that the major use of nickel in 1913 was for armour plate and ordnance. In 1933, with a greater total consumption, the nickel used throughout the world for military and naval purposes was probably not over five per cent. of the whole. The large use for war materials has been replaced by industrial applications.

The approximate percentages of the uses of nickel in its present (1933) principal diversified industrial applications are summarized in the following Table I:

TABLE I
World Market
Approximate Percentages of Nickel Consumed in Its Principal Applications

Alloy Steels used in Motor Cars, Trucks and Buses	20%
Nickel Silvers (the present name for German-Silver) and Nickel-Copper Alloys for a multitude of uses	18%
Pure Rolled Nickel in the form of rods, strip, sheets, wire, and tubes, used largely in the Radio, in the Chemical Industries, and for Coinage	17%
Alloy Steels, inclusive of Stainless Steel, used in Railway Equipment, Farm Implements, General Machinery, and numerous miscellaneous applications	15%
Nickel for Plating and as undercoat in Chromium Plating	10%
Monel Metal used for many Engineering Purposes and for Household Equipment	9%
Alloy Cast Irons—Castings of all kinds	4%
Miscellaneous Uses, including Magnetic Alloys, Nickel Brasses, Nickel Bronzes, Nickel-Aluminum Alloys and White Gold	4%
Heat Resistant and Electrical Resistance Alloys	3%
TOTAL	100%

Nickel is commercially available in various forms, as shown in the following Table II:

TABLE II

Forms of Nickel Commercially Available

No.	*% Ni.*	*Primary Nickel Products*
A	99.90	Electrolytic Nickel of highest grade, for remelting in alloy production such as steels, nickel silvers, etc.
B	99.80	Pellets, for remelting in the production of steels and other alloys.
C	99.00	25 lb. and 50 lb. pigs, for remelting in the production of steels.
D	99.00	Shot Nickel, for remelting in the production of alloys.
E	99.50	Reduced, or grain, Nickel, for solution in acids in nickel salts production.
F	92.00	Low melting point "F" Shot and Ingot Nickel, for ladle and cupola additions to cast irons.
G	97.00	High carbon "A" Shot and Ingot, for additions to cast irons.
H	99.50	Nickel rondelles, for remelting in the production of alloys.
I	56.00	Nickel-Copper-Chromium pigs, for the production of corrosion resistant cast irons.
J	77.50	Nickel oxide, green and black.
K	99.00	Nickel anode bars, for nickel plating.
L	95/97.00	Nickel anodes, for nickel plating.
M	92/95.00	Nickel anodes, for nickel plating.
N	20.80	Nickel Sulphate, crystallized, for nickel plating.
O	14.80	Nickel Ammonium Sulphate, crystallized, for nickel plating.
P	22.50	Nickel Chloride, for nickel plating.
Q	44.00	Nickel Carbonate, for catalyst.
R	50.00	Nickel-Aluminum, for catalyst.
S	69.00	Monel Metal, in sheets, bars, rods, tubes, wire, strip, ingots, for fabricating and casting.
T	99.00	Nickel, in sheets, bars, rods, wire, tubes, strip, castings and special sections, for fabrication.
U	50.00	Copper-Nickel Shot of low melting point, for addition to bronzes.
V	20.00	Nickel Silver pigs, for castings.
W	30.00	Nickel-Copper-Iron pigs, for castings (Everbrite).
X	99.00	Nickel Powder—100 mesh and finer, for pressing and sintering of die formed shapes.

Folded in the back of this book (page 75) are three charts. The first shows the world's production of metallic nickel from 1850 to 1933. The second shows published prices of metallic nickel from 1840 to 1933. The third shows a comparison between the published prices of nickel, copper, lead, zinc and tin, from 1903 to 1933.

TABLE III

Growth of Industrial Uses of Nickel

	Date of Origin	*Names Associated with Origin*	*Substantial Use Began*
GROUP I			
Nickel Silvers	"Paktong," very early in China	Geitner, Henninger, Merry and Askin	1830
Coinage	235 B. C.	Bactrian Coin	1850
Nickel Plating	1843	Boettger	1870
Wrought Nickel Steels	1889	Marbeau, Riley, Hall, and Hadfield	1890
GROUP II			
Nickel-Copper Alloys (other than coinage and Monel Metal type)	1895	Feussner and Lindeck	1905
Nickel Catalyzers	1896	Sabatier and Senderens	1905
Nickel for Storage Batteries	1901	Edison	1906
Monel Metal	1905	R. C. Stanley	1910
Heat Resisting and Electrical Resistance Alloys	1906	Marsh and Placet	1911
GROUP III			
Malleable Nickel	1865	Wharton and Fleitmann	1912
Cast Nickel Steels	1896	Wedding	1915
Nickel Bronzes	1900	Clamer	1920
Corrosion Resistant Steels	1915	Strauss, Pasel, Johnson	1920
Nickel-Iron Alloys	1895	Dumas, Benoit, Guillaume	1925
Nickel Cast Irons	1907	Guillet	1925
GROUP IV			
Nickel Silvers with low nickel contents (Nickel Brasses)	1912	Guillet	1926
Light Alloys ("Y" and "RR")	1921	Nat'l Phys. Lab. and Rolls-Royce	1927
Special Cast Irons ("Ni-Resist," "Ni-Tensyliron," "Ni-Hard")	1928	The International Nickel Company, Inc.	1930
Inconel	1930	The International Nickel Company, Inc.	1932
Nickel-Clad Steel	1929	The International Nickel Company, Inc.	1932

Group 1	In substantial use in 1900	Groups 1, 2, 3	In substantial use in 1926
Groups 1 and 2	In substantial use in 1918	Groups 1, 2, 3, 4	In substantial use in 1934

If we take the arbitrary classification of Table III (1) as a basis of analysis, we note a series of twenty definite classes of nickel products and applications in use today, as compared with the eleven in 1918 and four in 1900. Furthermore, there is, within several of these industrial classes, a much greater diversification today than ever before, particularly in nickel steels, nickel cast irons, nickel-chromium alloys, nickel-copper alloys, Monel Metal and malleable nickel.

It is thus obvious that nickel has a very wide field of application. There are probably few metals with so great a variety of uses. Furthermore, these nickel products have taken their place as recognized standard materials with a constantly increasing industrial demand.

A few words may be said concerning these different groups of industrial nickel products, with particular reference to the more recent developments and to the engineering reasons for their use.

WROUGHT NICKEL STEELS

Nickel steels comprise the largest tonnage of industrial nickel products. Although the detail of their use has changed considerably during the past fifteen years, in consequence of the reduction in use in armour plate and ordnance, the nickel steels have always been of first importance.

Tables IV and V show the standard classification of the American nickel, nickel-chromium, nickel-molybdenum and nickel-chromium-molybdenum steels by chemical composition, as adopted by

(1) Some of the details in this table must be accepted as rather rough approximations, made for the purpose of presenting a clear and simple picture of the nickel market, past and present.

the Society of Automotive Engineers. The requirements of the automotive industry have been so well covered by these specifications that for many years no major changes or additions were found to be necessary.

TABLE IV

Composition of S.A.E. Nickel Steels

S.A.E. Steel No.	*Carbon Range*	*Manganese Range*	*Phosphorus Max.*	*Sulphur Max.*	*Nickel Range*
2015	0.10–0.20	0.30–0.60	0.04	0.05	0.40–0.60
2115	0.10–0.20	0.30–0.60	0.04	0.05	1.25–1.75
2315	0.10–0.20	0.30–0.60	0.04	0.05	3.25–3.75
2320	0.15–0.25	0.30–0.60	0.04	0.05	3.25–3.75
2330	0.25–0.35	0.50–0.80	0.04	0.05	3.25–3.75
2335	0.30–0.40	0.50–0.80	0.04	0.05	3.25–3.75
2340	0.35–0.45	0.50–0.80	0.04	0.05	3.25–3.75
2345	0.40–0.50	0.50–0.80	0.04	0.05	3.25–3.75
2350	0.45–0.55	0.50–0.80	0.04	0.05	3.25–3.75
2512	max. 0.17	0.30–0.60	0.04	0.05	4.75–5.25

The rapid increase in popularity of the nickel-molybdenum and nickel-chromium-molybdenum steels during the past few years has made their inclusion desirable and the Society therefor proposes to add the seven steels distinguished by asterisks in Table V to the existing specifications.

TABLE V

Composition of S.A.E. Nickel-Chromium, Nickel-Molybdenum, and Nickel-Chromium-Molybdenum Steels

S.A.E. Steel No.	*Carbon Range*	*Manganese Range*	*Phosphorus Max.*	*Sulphur Max.*	*Nickel Range*	*Chromium Range*	*Molybdenum Range*
3115	0.10–0.20	0.30–0.60	0.04	0.05	1.00–1.50	0.45–0.75	....
3120	0.15–0.25	0.30–0.60	0.04	0.05	1.00–1.50	0.45–0.75	....
3125	0.20–0.30	0.50–0.80	0.04	0.05	1.00–1.50	0.45–0.75	....
3130	0.25–0.35	0.50–0.80	0.04	0.05	1.00–1.50	0.45–0.75	....
3135	0.30–0.40	0.50–0.80	0.04	0.05	1.00–1.50	0.45–0.75	....
3140	0.35–0.45	0.50–0.80	0.04	0.05	1.00–1.50	0.45–0.75	....
x3140*	0.35–0.45	0.60–0.90	0.04	0.05	1.00–1.50	0.60–0.90	....
3145	0.40–0.50	0.50–0.80	0.04	0.05	1.00–1.50	0.45–0.75	....
3150	0.45–0.55	0.50–0.80	0.04	0.05	1.00–1.50	0.45–0.75	....
3215	0.10–0.20	0.30–0.60	0.04	0.045	1.50–2.00	0.90–1.25	....
3220	0.15–0.25	0.30–0.60	0.04	0.045	1.50–2.00	0.90–1.25	....
3230	0.25–0.35	0.30–0.60	0.04	0.045	1.50–2.00	0.90–1.25	....
3240	0.35–0.45	0.30–0.60	0.04	0.045	1.50–2.00	0.90–1.25	....
3245	0.40–0.50	0.30–0.60	0.04	0.045	1.50–2.00	0.90–1.25	....
3250	0.45–0.55	0.30–0.60	0.04	0.045	1.50–2.00	0.90–1.25	....
3312	max. 0.17	0.30–0.60	0.04	0.045	3.25–3.75	1.25–1.75	....
3325	0.20–0.30	0.30–0.60	0.04	0.045	3.25–3.75	1.25–1.75	....
3335	0.30–0.40	0.30–0.60	0.04	0.045	3.25–3.75	1.25–1.75	....
3340	0.35–0.45	0.30–0.60	0.04	0.045	3.25–3.75	1.25–1.75	....
3415	0.10–0.20	0.30–0.60	0.04	0.045	2.75–3.25	0.60–0.95	....
3435	0.30–0.40	0.30–0.60	0.04	0.045	2.75–3.25	0.60–0.95	....
3450	0.45–0.55	0.30–0.60	0.04	0.045	2.75–3.25	0.60–0.95	....
4340*	0.35–0.45	0.50–0.80	0.04	0.05	1.50–2.00	0.50–0.80	0.30–0.40
x4340*	0.35–0.42	0.60–0.80	0.04	0.05	1.50–2.00	0.60–0.80	0.30–0.40
4345*	0.40–0.50	0.50–0.80	0.04	0.05	1.50–2.00	0.60–0.90	0.15–0.25
4615	0.10–0.20	0.40–0.70	0.04	0.05	1.65–2.00	....	0.20–0.30
4620*	0.15–0.25	0.40–0.70	0.04	0.05	1.65–2.00	....	0.20–0.30
4640*	0.35–0.45	0.50–0.80	0.04	0.05	1.65–2.00	....	0.20–0.30
4815*	0.10–0.20	0.40–0.60	0.04	0.05	3.25–3.75	....	0.20–0.30
4820*	0.15–0.25	0.40–0.60	0.04	0.05	3.25–3.75	....	0.20–0.30

*Tentative specifications.

x4340 denotes an electric furnace steel, whereas 4340 is intended to apply to open hearth steel.

The silicon is 0.15-0.30 for basic open hearth, and 0.15 min. for electric furnace and acid open hearth steels.

The following Tables VI to XIII give the compositions of some of the principal British, German, French and Italian nickel, nickel-chromium and nickel-chromium-molybdenum steels:

TABLE VI
Composition of British Nickel Steels

Carbon Range	*Manganese Range*	*Phosphorus Maximum*	*Sulphur Maximum*	*Nickel Range*
max. 0.15	0.20–0.60	0.050	0.050	2.50–3.50
max. 0.15	max. 0.40	0.050	0.050	4.50–6.00
0.08–0.14	max. 0.35	0.050	0.050	4.60–5.20
0.10–0.15	0.20–0.60	0.050	0.050	2.75–3.50
0.10–0.15	max. 0.40	0.050	0.050	4.75–5.50
0.25–0.35	0.35–0.75	0.050	0.050	2.75–3.50
0.35–0.45	0.80–1.20	0.050	0.050	0.90–1.10
0.35–0.45	0.50–0.80	0.050	0.050	3.25–3.75

These steels may contain up to 0.30 chromium, except the third steel, which is limited to 0.10.

Silicon content 0.30 max.

TABLE VII
Composition of British Nickel-Chromium and Nickel-Chromium-Molybdenum Steels

Carbon Range	*Manganese Range*	*Phosphorus Maximum*	*Sulphur Maximum*	*Nickel Range*	*Chromium Range*	*Molybdenum Range* (*)
0.08–0.14	0.30–0.60	0.050	0.050	3.25–3.75	0.60–1.00	....
0.14–0.18	0.35–0.45	0.050	0.050	4.00–4.50	1.00–1.30	....
0.22–0.28	0.35–0.65	0.050	0.050	2.75–3.50	1.00–1.40	.65 max.
0.25–0.32	0.35–0.60	0.050	0.050	3.75–4.50	1.00–1.50	.65 max.
0.25–0.35	0.45–0.70	0.050	0.050	3.00–3.75	0.50–1.00	.65 max.
0.35–0.42	0.45–0.65	0.050	0.050	1.25–1.75	0.75–1.25	....

*Optional.

Silicon content 0.30 max.

TABLE VIII
Composition of German Nickel Steels

Carbon Range	*Manganese Range*	*Phosphorus Maximum*	*Sulphur Maximum*	*Nickel Range*
0.10–0.17	Up to 0.50	0.035	0.035	1.25–1.75
0.10–0.17	0.40–0.50	0.035	0.035	3.00–3.50
0.10–0.17	0.40–0.50	0.035	0.035	4.90–5.30
0.25–0.35	0.40–0.60	0.035	0.035	2.90–3.30
0.25–0.35	0.60–0.80	0.035	0.035	4.90–5.30

Nickel Steels and Nickel Chromium Steels may contain, in addition, up to 0.75 Molybdenum.

Silicon content 0.35 max.

TABLE IX
Composition of German Nickel-Chromium Steels

Carbon Range	*Manganese Range*	*Phosphorus Maximum*	*Sulphur Maximum*	*Nickel Range*	*Chromium Range*
0.10–0.17	Up to 0.50	0.035	0.035	2.25–2.75	0.55–0.95
0.10–0.17	Up to 0.50	0.035	0.035	3.25–3.75	0.55–0.95
0.10–0.17	Up to 0.50	0.035	0.035	4.25–4.75	0.90–1.10
0.20–0.27	0.40–0.80	0.035	0.035	3.25–3.75	0.55–0.95
0.25–0.32	0.40–0.80	0.035	0.035	1.25–1.75	0.30–0.70
0.25–0.32	0.40–0.80	0.035	0.035	2.25–2.75	0.55–0.95
0.27–0.35	0.40–0.80	0.035	0.035	3.25–3.75	0.55–0.95
0.30–0.40	0.40–0.80	0.035	0.035	4.25–4.75	1.10–1.50
0.32–0.40	0.40–0.80	0.035	0.035	0.75–1.25	0.30–0.70

Nickel Steels and Nickel Chromium Steels may contain, in addition, up to 0.75 Molybdenum.

Silicon content 0.35 max.

TABLE X
Composition of French Nickel Steels

Type of Steel	*Carbon*	*Nickel*
Mild Case-Hardening Steels	Up to 0.18	1.80–2.50
	Up to 0.18	3.00–4.00
	Up to 0.18	5.00–7.00
Semi-Mild Steels	0.13–0.23	1.00–2.00
	0.15–0.20	3.00
	0.15–0.20	5.00
Semi-Hard Steels	0.20–0.30	2.80–3.50
	0.20–0.35	5.00
	0.23–0.30	1.70–3.20
	0.25–0.30	1.00
	0.30–0.40	1.80–2.20

Nickel Steels and Nickel Chromium Steels may contain, in addition, up to 0.75 Molybdenum.

TABLE XI
Composition of French Nickel-Chromium Steels

Type of Steel	*Carbon*	*Nickel*	*Chromium*
Mild Case-Hardening Steels	0.08–0.12	2.00–3.50	0.60–1.00
	0.10–0.16	4.20–4.50	1.20–1.60
	0.10–0.16	5.00–6.00	1.50–2.00
	0.10–0.20	2.50–3.20	0.50–0.80
	0.15–0.18	3.50–4.20	0.65–0.80
Semi-Hard Steels	0.15–0.30	2.60–2.80	0.60–0.80
	0.20–0.30	3.50–4.00	0.30–0.65
	0.25–0.35	2.70–3.50	0.60–1.30
	0.30–0.35	2.50–3.00	0.60–0.80
	0.33–0.45	0.80–2.40	0.50–1.00
Hard Steels	0.40–0.55	2.70–3.50	0.60–1.50
	0.50–0.65	1.30–1.70	0.60–0.80
	0.60	2.60–2.80	1.40–1.60
	0.60–0.65	2.60–2.80	0.70–0.80
Self-Hardening Steels	0.12–0.16	5.50–6.00	1.50–2.00
	0.15	5.00	1.00
	0.20–0.25	4.70–6.00	1.30–2.00
	0.28–0.40	3.50–5.00	1.20–2.00

Nickel Steels and Nickel Chromium Steels may contain, in addition, up to 0.75 Molybdenum.

TABLE XII
Composition of Italian Nickel Steels

Carbon	*Nickel*
0.10–0.15	0.50
0.10–0.15	2.00
0.10–0.18	3.00–3.50
0.10–0.20	5.00
0.20	3.00
0.20	4.50–5.50
0.20–0.30	3.00
0.20–0.30	5.00
0.25–0.35	2.00
0.25–0.40	1.00–2.00
0.30–0.40	3.00

Nickel Steels and Nickel Chromium Steels may contain, in addition, up to 0.75 Molybdenum.

TABLE XIII
Composition of Italian Nickel-Chromium Steels

Carbon	*Nickel*	*Chromium*
0.08–0.16	2.50	0.75
0.08–0.16	3.50	0.75
0.08–0.16	4.50	1.20
0.10–0.20	3.00	0.70
0.15–0.20	2.75–3.25	0.80
0.20–0.30	2.50	0.50
0.25–0.30	1.00	1.00
0.25–0.40	2.00	1.00
0.30	3.00	1.00
0.30–0.40	2.50	0.70
0.30–0.40	4.50	1.50
0.45	3.00	1.50
0.50–0.60	1.50	0.80

Nickel Steels and Nickel Chromium Steels may contain, in addition, up to 0.75 Molybdenum.

There are other nickel steels, not included in the foregoing tables, which find important uses in industry. These include the low carbon 2% or 2½% nickel steels for boiler plate, also welded pressure vessel construction for operations at low temperatures, and the low carbon 2¾% nickel steels for railroad forgings.

Industrial applications are found also for a variety of complex nickel-containing steels with different proportions of chromium, molybdenum, vanadium, etc., to meet special requirements.

The dependability, high strength and dynamic toughness of these steels, which can be further enhanced by appropriate heat treatments, have led to their being used in practically all the principal industrial fields, to mention briefly only the following:

Automotive and Aviation Industries.—For rear axles and transmission gears, rear and front axles, crank and cam shafts, frames, roller bearings, silent chains, bolts, connecting rods, steering knuckles.

Heavy Mill Machinery.—For hydraulic press columns, crossheads, hammer piston rods, cast and forged rolls, die-blocks, shear blades.

Prime Movers and Power Machinery.—For turbine rotor forgings, turbine blading, reduction gears, marine crank and turbine shafts, pump shafts, roller bearings, chain drive, high-pressure steam valve bodies and trim.

Railways.—For locomotive frame castings, forged main and side rods, valve gear, axles, roller bearings, boiler plate, boiler tubes, staybolts, engine bolts, cast crossings, frogs and switch points.

Mining and Excavating Machinery.—For cast racks and pinions, cast crusher jaws, forged and rolled shafts, cast and forged gears. Recently their application to mine cages and cables has formed the subject of special studies.

Tools.—For die-blocks, punches, track chisels, band and disc saws, oil well drilling-bits, cutters, jaws and couplers, shovels.

Machine Tools.—For shafts and spindles, gears, chains.

Agricultural Machinery.—For cast tractor shoes, sprockets, gears, shafts.

Bridge Construction.—For structural plates and shapes, eye-bars.

General Machinery.—For heat-treated forgings, gears, axles, shafts, chains, roller and ball bearings.

Military and Naval.—For armour and deck plate, gun forgings.

CAST NICKEL STEELS

Cast nickel alloy steels fulfill the industrial requirements for materials of moderate cost, showing high strength and ductility, as well as resistance to shocks, fatigue, and wear. Their compositions and heat treatments depend on the size and shape of the castings and the working conditions.

Nickel alloy steel castings are produced by many foundries and the compositions utilized for particular applications will be found to vary somewhat, depending upon the source of manufacture, etc. The types most commonly employed at present are given in Table XIV and the following notes cover their more important fields of applications:

Steels (1) are especially recommended for locomotive frames; castings for mining, excavating and steel mill machinery; ship castings and other parts subjected to shock and fatigue stresses.

Steels (2) are adapted for miscellaneous railroad castings, large gears not subjected to severe abrasion, steel mill machinery, crusher frames, tractor and power shovel frames, and other parts requiring higher strength and elastic properties than those of the steels (1).

TABLE XIV
Typical Compositions of Cast Nickel Steels

No.	*Carbon*	*Manganese*	*Nickel*	*Chromium*	*Molyb-denum*	*Vanadium*
1	Max. 0.20	0.60–0.90	Min. 2.00			
2	0.20–0.30	0.70–1.00	Min. 2.00			
3	0.20–0.40	1.00–1.25	0.75–1.25			
4	0.30–0.40	0.75–0.85	1.30–1.50	0.85–0.95		
5	0.35–0.50	0.60–0.80	1.25–1.75	0.60–0.90		
6	0.35–0.50	0.50–0.75	2.00–2.80	0.85–1.10		
7	0.20–0.30	0.75–1.00	1.50–1.60			0.10–0.12
8	0.30–0.35	0.60–0.80	1.25–1.50		0.30–0.35	
9	0.25–0.35	0.55–0.85	1.75–2.25	0.65–0.90	0.15–0.25	
10	0.30–0.40	0.60–0.80	1.75–2.25	0.70–0.90		

Steels (3), pearlitic nickel-manganese steels, are used for structural castings in tractors, motor trucks, road building machinery, electrical machinery, and other highly stressed machine parts.

Steels (4) are used mainly for oil well tools, sheaves, sprockets, tractor shoes, gears, cams and other highly stressed castings.

Steels (5), oil quenched and tempered, are used for hardened gears, cams, rollers, sprockets and abrasion resistant castings, such as bucket teeth, small crusher jaws, conveyor chain links, etc.

Steels (6) are particularly suited for highly stressed gears, pinions, rollers, sprockets, and miscellaneous machine parts of medium and large sections.

Steels (7) are used for medium- and large-section castings for locomotives, rolling mill machinery, etc., highly stressed gears and other parts for power shovels and other machinery subjected to rugged service.

Steels (8) are used successfully for highly stressed parts such as rolling mill machinery castings, heavy duty gears, pinions of large size and mining machinery castings.

Steels (9), with a wide range of properties obtainable through specific heat treatments, are suitable for structural castings demanding high strength and good ductility.

Steels (10) are used for castings of high creep resistance and strength at elevated temperatures, particularly in power plants and oil refineries.

CORROSION-RESISTANT STEELS

Early in the history of nickel steels, investigators became aware of the corrosion-resistance of steels containing from twenty to thirty per cent. nickel. There has been considerable use of such materials for various purposes where strength and substantial resistance to corrosion are required. More recently, however, chromium-nickel corrosion-resistant steels have been developed, particularly the 18% chromium 8% nickel type, which has come into wide use in the United States and other countries. This steel, in addition to its chemical resistance, has excellent mechanical properties with great strength and high fatigue resistance.

Recently, interesting modifications of this alloy have been made, consisting in incorporating small quantities of additional elements (titanium, columbium, molybdenum, silicon, tungsten, vanadium, zirconium, etc.) for "stabilizing the 18/8 alloys."

Progress in the welding of the 18/8 alloys has contributed greatly to the development in the uses of this important type of alloy.

The principal applications for these corrosion-resistant alloys are for building trim, household cooking utensils, marine fittings, automobile hardware and fittings, power equipment, submarine periscope tubes, turbine blading, chemical apparatus and miscellaneous parts of out-door equipment.

HEAT RESISTING AND ELECTRICAL RESISTANCE ALLOYS

The industrial demand for alloys to resist high temperatures has led to the development of a series of appropriate iron-chromium-nickel alloys, which are now successfully used in a great variety of applications. They are chemically and mechanically stable at temperatures as high as 1,800° F., are stronger than steels at these temperatures and resist oxidation. They insure continuity of operations in high temperature processes and have become especially valuable for carburizing boxes, rabble arms and shoes in metallurgical roasting furnaces, shafts and discs of continuous annealing and heat-treating furnaces, interior construction generally in enameling and heating furnaces, retorts and tubes in the chemical industries, and for fuel carbonization and heat exchangers.

The growing electrical industry, especially the electrical heating (electric furnaces, domestic heating appliances, and the like) required the development of a series of electrical-resistance alloys, particularly the nickel-chromium and nickel-chromium-iron alloys, the typical examples of which are the Chromels, Nichromes, Brightray, Dullray and Glowray. They are used mainly in wire form for domestic heating units, toasters, irons, grills, percolators, etc.; for electric heating furnaces; for pyrometers and rheostats.

At present, there are nearly 100 trade-named heat- and electrical-resistant alloys.

NICKEL-IRON ALLOYS

There are numerous ferro-nickel alloys and they exhibit the greatest diversification of characteristics and properties. The best known are those of the Invar type and the magnetic alloys.

Invar Type Alloys.—The most useful property of the alloys with 30 to 40% nickel is their exceptionally low coefficient of expansion. Charles Guillaume of the International Bureau of Weights and Measures, Paris, in the search of an alloy of minimum coefficient of expansion for a length standard, succeeded in obtaining an alloy with 36% nickel, which under ordinary changes in temperature did not undergo any appreciable dimensional changes, hence its specific name of "Invar" (part of the word invariable).

Improvements in the purity of the alloy and in the heat treatment have reduced its coefficient of expansion to a negligible value. The United States Bureau of Standards has found that properly made Invar tapes will vary less than one part in 500,000 after six months use in the field.

Invar is now used not merely for length standards, but also for a series of industrial applications, such as measuring tapes, in instruments requiring fixed distances between points under varying temperatures, in the watch making industry, for bi-metallic thermostats, and, more recently, for light alloy piston struts.

The name Invar is applied now quite loosely to the iron-nickel alloys with 30 to 40% nickel.

By adding other elements, related alloys are obtained, the best known being "Elinvar" of the composition: 33–35% nickel, 53–61% iron, 4–5% chromium, 1–3% tungsten, 0.5–2% manganese, 0.5–2% silicon, 0.5–2% carbon, and so named because of its invariable elasticity. It is used principally for watch springs and other precision instruments.

Magnetic Alloys.—The striking effect of varying percentages of nickel on the magnetic behaviour of nickel-iron alloys, has been observed from the beginning of the systematic study of these combinations. In 1920, T. D. Yensen of the Westinghouse Electric & Manufacturing Company, presented before the American Institute of Electrical Engineers a comprehensive review of the magnetic properties of these alloys. Since then further research in this field has led both to wider use for the older alloys and to the development of new combinations with still different magnetic characteristics.

Among the best known magnetic alloys are "Permalloy," "Mu-Metal," "Hipernik" and "Perminvar." Permalloy (typical composition: 78.5% nickel and 21.5% iron) has magnetic permeabilities at low field strengths, which are many times greater than any hitherto known. The success of this alloy as loading material for submarine cables is well known. MuMetal is a similar British alloy containing 74% nickel, 20% iron, 5.3% copper and 0.7% manganese. Hipernik, a 50–50 nickel-iron alloy, has its most important application in current transformers. Perminvar (45% nickel, 30% iron and 25% cobalt) is a magnetic alloy widely used in telephone installations.

Non-magnetic Alloys.—Contrasted with the above group is a series of nickel-steel alloys containing 15 to 25% nickel and frequently some chromium. These non-magnetic alloys are valuable chiefly in electrical machinery on account of their good mechanical properties and their freedom from ferro-magnetism.

Steels containing up to 25% Nickel together with additions of Chromium, Tungsten, Molybdenum and Silicon are rapidly gaining favour where a non-magnetic Steel having high physical properties is required.

NICKEL CAST IRONS

Among the latest ferrous nickel products are the nickel cast irons. For many years something has been known about the effect of nickel in grey cast iron, and it was in 1907 that Leon M. Guillet presented before the French Academy the results of the first systematic study of the effects of nickel on cast iron. The industrial applications of nickel cast irons were greatly limited up to 1925. The present development in their uses is the direct result of the technical activities of The International Nickel Company of Canada, Limited, in this field.

Although the consumption of nickel for this purpose is still small (4% in 1933), it is growing rapidly, and it may be said that the manufacture of nickel cast irons appears to offer a substantial outlet for nickel in the future.

Tables XV and XVI, appearing on the following page, give the chemical compositions of the commonly used nickel and nickel-chromium cast irons.

The alloy cast irons now find real applications for automobile and truck cylinders, sleeves, liners and pistons, pump, steam compressor and ammonia cylinders and liners, piston rings, oil and gas engine cylinders, hard gears and cams, thin-section manifold castings, resistance grids, hardware, machine tool table and bench castings, grey iron wheels, flange couplings, etc.

TABLE XV
Chemical Composition of Nickel Cast Irons

Nickel	*Cast Iron*
0.50	Balance
0.75	Balance
1.00	Balance
1.25	Balance
1.50	Balance
2.00	Balance
3.00	Balance
5.00	Balance

TABLE XVI
Chemical Composition of Nickel-Chromium Cast Irons

Nickel	*Chromium*	*Cast Iron*
0.75	0.35	Balance
1.00	0.35	Balance
1.25	0.30	Balance
1.25	0.45	Balance
1.25	0.50	Balance
1.75	0.75	Balance
2.00	0.60	Balance
2.50	0.50	Balance
2.75	0.70	Balance
3.00	1.00	Balance

SPECIAL NICKEL CAST IRONS

Experimental work during the last few years, carried out by The International Nickel Company of Canada, Limited, has resulted in the development of three special cast irons: a corrosion-resistant cast iron "Ni-Resist," a strong iron "Ni-Tensyliron," and a hard cast iron "Ni-hard."

"Ni-Resist" is a nickel-copper-chromium cast iron of the composition range: 2.75-3.10% total carbon, 1.25-2.0% silicon, 0.1-1.5% manganese, 0.04-0.12% sulphur, 0.04-0.30% phosphorus, 12.0-15.0% nickel, 5.0-7.0% copper, 1.5-4.0% chromium. It is corrosion-resistant with good thermal stability and is non-magnetic. It is successfully used in a great variety of applications, especially for oil refinery equipment, power plant and laundry machinery and household appliances. It is also used extensively in the chemical, automotive, electrical, refrigeration, brewing, canning, paper, sugar, salt, soap, ceramics, and allied industries.

"Ni-Tensyliron" is a nickel-bearing grey cast iron of exceptionally high strength having the following composition range: 2.5-3.15% total carbon, 0.5-0.9% manganese, maximum 0.15% phosphorus, maximum 0.12% sulphur, 1.20-2.75% silicon, 1.0-4.0% nickel, according to the size and thickness of the casting. In some special instances, 0.35% to 0.78% chromium or 0.55 to 0.70% molybdenum may be added. The tensile strength is between 55,000 and 88,000 lbs./sq. in. and the Brinell hardness between 240 and 320. Typical applications include gears, turbine castings and rotors, valves and fittings, sheaves, bushings, pressure housings, heavy machinery frames, etc.

"Ni-Hard" is a nickel-chromium cast iron for chilled or white

iron castings applications, having the composition range: 2.7-3.6% total carbon, 0.35-0.50% manganese, maximum 0.2% phosphorus, maximum 0.12% sulphur, 0.5-1.95% silicon, 4.25-4.75% nickel, 1.4-1.6% chromium, with a Brinell hardness up to 700, great resistance to wear and deformation, and a lesser susceptibility to fracture under loads and shocks than plain chilled iron. Typical applications include mill balls, rolls, crushers, grinders, pulverizers, car wheels, plow-shares and the like.

NICKEL SILVERS

Nickel silver (German-silver) is one of the oldest established uses of nickel and still is a very substantial one. The industrial applications of this material have not changed much in recent times. There is, however, one development worthy of notice; namely, the development of compositions of nickel silver that can be hot worked. The hot-rolling varieties are not essentially different from the other varieties in their valuable characteristics of appearance, corrosion resistance, and ready fabricability, but they offer promise of somewhat cheaper production.

The compositions of nickel silver vary within quite broad limits, as can be seen by Table XVII appearing on following page.

There are today on the market more than one hundred and fifty trade-named nickel silvers.

Nickel silvers are widely used as a base for silver plated tableware and filled jewelry, flat keys, plumbing fixtures, architectural trim, building and marine hardware, lighting fixtures, and decorative trim generally.

TABLE XVII
Composition of Typical Nickel Silvers

Nickel	*Copper*	*Zinc*	*Others*
10	45	45	
10	65	25	
12	50	18	2 tin, 18 lead
12	54	21	2.5 tin, 10.5 lead
12	62	26	
15	40	45	
15	50	35	
15	64	21	
18	58	24	
18	65	17	
20	55	25	
20	60	20	
20	75	5	
22	61	12	3 aluminum, 2 lead
24	41	35	
25	50	25	
25	55	20	
26	33	40	1 iron
30	47	23	
31	26	42.5	0.5 iron
31	47	21	1 tin

NICKEL BRONZES

Historically, it is interesting to mention that a British Patent had been issued to G. Ranitzsch as far back as 1891 for an alloy containing 67% copper, 20% zinc, 6% tin, 4% nickel, 3% aluminum, to be used for soles and heels of boots and shoes.

Perhaps the first application of nickel in the brass foundry was its use in high-lead bearing-bronzes, to prevent lead segregation.

Such an alloy was introduced by G. H. Clamer, about 1900, in the bronze commonly known as "Ajax plastic bronze," the demand for which has grown steadily in recent years.

A series of trade-named nickel bronzes is now on the market.

Table XVIII shows the average compositions of the most commonly used bronzes:

TABLE XVIII
Composition of Nickel Bronzes

Nickel	*Copper*	*Zinc*	*Tin*	*Lead*
1	88.5		10	0.5
1	84	7	2.5	5.5
1	64		5	30.0
3	87	5	4	1.0
4	89	3	4	
5	88	2	5	
5	84	2	9	

Soundness, improved toughness and strength at atmospheric and steam temperatures are among the effects which make nickel valuable in bronzes. These bronzes are used mainly for valve castings, worm gears, bearings, rolling mill housing nuts and ship propellers.

Experimental work carried out by E. M. Wise and J. T. Eash at the Bayonne Laboratory of The International Nickel Company, Inc., on the heat treatment and aging characteristics of nickel bronzes, has shown that exceptionally good properties can be imparted to nickel bronzes. Thus, it is possible to obtain sand-cast nickel bronzes which, when annealed and aged, develop a strength in excess of 90,000 lbs./sq. in., coupled with an elongation of 15%. Similarly, wrought nickel bronzes, when annealed and aged, develop a tensile strength of 135,000 lbs./sq. in., and 170,000 lbs./sq. in. when hard-rolled and aged.

Of specific interest are the bronzes with 7.5% nickel and 8% tin. The high properties of these heat-treatable and age-hardening bronzes, their amenability to cold working in the soft state, their ready machinability, particularly after slow cooling, and their relatively low cost, make them applicable wherever properties superior to the usual bronzes are required.

NICKEL SILVERS WITH LOW NICKEL CONTENTS
(Nickel Brasses)

The simple and complex nickel brasses contain up to 5% nickel, although some may contain higher percentages. There are also modifications of these compositions containing manganese and iron. Table XIX shows the average compositions of the most commonly used nickel brasses:

TABLE XIX
Composition of Nickel Brasses

Nickel	*Copper*	*Zinc*	*Others*
1.5	54	44	0.5 iron
2.5	55	42.5	
3.0	60	34	2 iron, 1 manganese
3.5	55	41.5	
5.0	52.5	39.5	3 manganese
5.0	60	24	2 iron, 5 aluminum, /4 lead
6.5	50.5	43	

There is now on the market a series of trade-named nickel brasses.

The addition of nickel to brass serves as a decolorizer and also to improve the mechanical properties and resistance to corrosion. This is leading to the gradual use of nickel brasses to replace plain brasses in industrial applications.

COPPER-NICKEL ALLOYS

Nickel and copper form solid solutions in all proportions, hence the large number of copper-nickel alloys of various compositions. Their manifold applications are due to their corrosion resistance, color and mechanical properties. Their principal uses are for condenser tubes, corrosion-resisting castings and sheets, valves and valve trims, coinage, etc. The following Table XX gives the composition of typical binary copper-nickel alloys:

TABLE XX
Composition of Typical Copper-Nickel Alloys

Nickel	*Copper*
2.5	97.5
3.0	97.0
5.0	95.0
12.0	88.0
15.0	85.0
20.0	80.0
25.0	75.0
30.0	70.0
40.0	60.0
45.0	55.0

In addition, there is a series of complex copper-nickel alloys, the compositions of which vary according to the service in which they are to be used.

An important alloy of this group, ordinarily known as "Constantan," contains approximately forty-five per cent. nickel with low manganese. This alloy combines high electrical resistivity with a low temperature coefficient of electrical resistance. In addition, it has a uniform and reproducible thermal electro-motive force toward either iron or copper. This property has led to the very general use of Constantan for electrical resistance wire, rheostats, etc., as well as for industrial thermocouples and thermo-electric pyrometers.

Hardenable Copper-Nickel-Silicon or Copper-Nickel-Aluminum Alloys are amongst the latest Alloys to receive attention and will no doubt play an important part in future engineering progress.

NICKEL COINAGE

Coinage is also one of the oldest uses of nickel. Mention has been made in the historical introduction of the use of nickel alloys for coinage. The principal interesting development in recent times has been the substitution of pure nickel coinage for the older nickel-copper coinage started about 1850. After the first pure nickel Swiss coin was struck in 1881, there was a long period before other governments adopted pure nickel for token coinage. In recent years however the advantages of nickel over the alloys in common use have become very generally known, and at present (October 1934) the following 28 governments, Table XXI, have minted pure nickel coins (75 issues representing 72 denominations):

TABLE XXI

Governments Where Pure Nickel Coins Have Been Issued

Albania	Germany	Mexico
Angola	Greece	Montenegro (now part of Yugoslavia)
Austria	Hungary	Morocco
Belgium	Kingdom of Iraq	Poland
Canada	Irish Free State	Siam
Danish West Indies	Italy	Switzerland
Free City of Danzig	Japan	Turkey
Ecuador	Latvia	Vatican State
Ethiopia	Luxembourg	Zanzibar
France		

Pure nickel is particularly suited for coinage because its toughness makes it difficult to counterfeit. Also, as pure nickel is magnetic, a counterfeit made from a non-magnetic alloy can be readily identified. Its wear resistance is of a high order and its inherent resistance to corrosion makes it a highly sanitary metal.

NICKEL PLATING

Nickel plating of iron and brass articles is perhaps the use best known to the general public. It is the form of nickel to which most minds turn when the word is mentioned.

Nickel plating has for many years been rather an art than a science. It is carried out in a multitude of small plating shops under a wide variety of conditions. Within the last few years there has been a definite indication of improvement in the practice, through better control of the plating conditions. This, with improved methods of preparation of work for plating, has resulted in substantially better nickel plated articles.

There is a recent definite trend toward heavier coatings of nickel. The old standard plate of nickel was not more than one ten-thousandth (0.0001) of an inch. In consequence, the plate was readily worn off. Many plating shops today are putting on a coating as heavy as one thousandth (0.001) of an inch. Experience has shown that the heavier coatings will endure and preserve their appearance very much longer. The universal demand for better nickel plating on automobiles has been responsible for this improvement in the art.

Nickel plating is applied now not only to ferrous products, but also to aluminum, zinc and their alloys. Successful chromium plating depends on the presence of a nickel plated underlay. Great progress has also been made during recent years in the electrodeposition of a series of nickel alloys. Coating by spraying with nickel and nickel alloys is being practised to a certain extent.

The building up of worn parts by the deposition of heavy nickel plates, Fescolizing—Fescol, Ltd., London—is now quite extensively applied.

NICKEL FOR STORAGE BATTERIES

The well-known Edison storage battery requires annually a substantial amount of nickel, both for the active chemical constituents of the cell and for the plating of the various steel parts of which it is made. This cell is increasing in popularity, being used today to a large extent for power units of automobile trucks, mine locomotives, railway cars, factory and warehouse trucks, as well as for emergency light and power stand-by service.

The Drumm battery, also of the nickel alkaline type, has been tested recently on the Irish Free State Railway with highly encouraging results.

The use of alkaline batteries for miners' lamps has resulted in greatly facilitating the mining operations, especially in the dangerous fire-damp collieries.

NICKEL CATALYZERS

Sabatier and Senderens discovered, about 1896, that finely divided nickel would catalyze the hydrogenation of unsaturated hydrocarbons. This discovery is now generally used for the production of solid edible fats from liquid unsaturated oils, such as cottonseed and peanut oils. Nickel for this purpose is sold chiefly in the form of nickel salts, particularly the carbonate and formate.

Nickel catalyzers are also being used for the cracking of petroleum, for the synthesis of higher hydrocarbons from acetylene, for the synthesis of alcohols from oxides of carbon, and also for the synthesis of ammonia and nitrates from nitrogen and its oxides.

Recently, Sperr has developed a process for the desulphurizing of domestic coal-gas, which promises to utilize in the future a moderate amount of nickel catalyzer.

LIGHT ALLOYS

The demand for light alloys with good mechanical properties, especially for the automotive and aviation industries, is steadily increasing.

"Y" alloy, developed by the National Physical Laboratory, in London, is the best known nickel-containing light alloy, having the strength of soft steel, good ductility and easily machinable. Range of composition: 1.8-2.3% nickel, 3.5-4.5% copper, 0.2-1.7% magnesium, maximum 0.75% iron, maximum 0.75% silicon, balance aluminum.

Another important type of nickel-containing light alloys are the "RR" alloys (Rolls-Royce), also known as "Hiduminium RR" alloys, developed in the Rolls-Royce Laboratory, of the composition: 0.2-1.5% nickel, 0.2-5.0% magnesium, 0.5-2.0% copper, 0.2-0.5% silicon, 0.7-1.5% iron, up to 0.25% manganese and titanium, balance aluminum.

MALLEABLE NICKEL

Nickel in forged or rolled form, or malleable nickel as it is usually called, has been known since 1865. Yet the extent of its manufacture has been small until lately, and its commercial uses have been restricted to wire, to coin blanks and to cooking utensils for restaurants and food processing plants. The recent development of seamless malleable nickel tubing has done much to further its use in the food and chemical industries. Other fields of application include marine construction (bolts and turbine blading); petroleum (strainers); radio (wires, screens, grids, plates) and electrical (spark plug wires and electrodes in photo-electric cells).

NICKEL CLAD STEEL

Related to the use of malleable nickel there has been recently introduced, on a commercial scale, mechanically applied nickel sheet to steel plates, for tanks and similar purposes. For economical reasons the cladding of cheap materials with more expensive materials has come to be accepted as a sound practice. Pure nickel lends itself very readily to bonding on iron or steel. Nickel clad steel plates of 3/16″ to 1″ thickness, with ten per cent. to twenty per cent. cladding, are being produced on a tonnage basis for storage tanks and chemical handling equipment, where a nickel surface is essential and a solid nickel plate would be too costly.

Progress in welding has contributed largely to the rapid development of nickel clad steel, which finds ready application in the chemical, dry cleaning, laundry, textile and food industries.

MONEL METAL

When certain of the Sudbury nickel-copper sulphide ores are smelted, bessemerized, roasted and the resulting oxides reduced, there is produced a natural malleable nickel-copper alloy. The average composition of this alloy is 67% nickel and 28% copper with the balance mainly iron but also containing small amounts of manganese, silicon, carbon (up to 0.26%) and sulphur (up to 0.035%). First produced in 1905, this alloy has the trade name "Monel Metal."

Persistent research into the technical suitability of Monel Metal for various industrial and engineering applications, and field service in solving fabrication and corrosion problems, have combined to build up a large and diversified consumption for this alloy. By increasing the iron and manganese contents from the standard composition, certain modifications of Monel Metal are now produced with special properties for particular uses. The addition of aluminum makes an alloy with especially high physical properties. This is known as "K" Monel Metal.

The construction of modern rolling mills devoted exclusively to the production of this and other high-nickel non-ferrous alloys and of malleable nickel, has been of the first importance in improving the quality of these products in malleability, conformity to engineering standards and finish.

The pleasing appearance of Monel Metal, its good mechanical properties and resistance to corrosion have won for it a wide market.

Its highly diversified applications include pickling equipment in the steel industry, dye vats in the textile field, sinks, hot-water boilers and other kitchen equipment in homes; various types of equipment in the processing of foods, and pump rods, valves, agitators and other applications in the petroleum, pulp and paper industries. Two striking uses are being made at Boulder Dam where the valve seats of the four great water gates and the grout stops in the concrete work are Monel Metal.

The erecting of modern rolling mills, devoted exclusively to the production of this high-nickel nickel-copper alloy and of malleable nickel has improved the quality of these products in malleability, conformity to engineering standards, and in finish and has opened the way to many fields of use.

Changes in the properties of Monel Metal have been made by increasing the iron and manganese contents, also by the addition of aluminum, to obtain a product of especially high physical properties, ("K" Monel Metal).

INCONEL

"Inconel" of the approximate composition 80% nickel, 14% chromium, 6% iron, recently developed by The International Nickel Company, Inc., presents the favourable combination of unusually high corrosion resistance, strength and good working properties. It can be easily forged, rolled and drawn, cast, machined and welded. Its properties are greatly enhanced by proper heat treatment. Inconel is particularly appropriate for dairy and other food-handling equipment, chemical apparatus, as well as equipment subject to severe weathering conditions.

MISCELLANEOUS

In addition to the above briefly outlined typical groups of nickel-containing materials, there is also a series of other nickel alloys for specific industrial uses, among which are die casting alloys, bearing alloys, white metal alloys, white gold, etc.

Approximately one thousand trade-named nickel-containing alloys are now on the market.

There is also an important application of nickel oxide, especially in the ceramic industry.

CONCLUSION

Converting swords into plow-shares has been a real experience in the nickel industry. From 1890 until the end of the World War, the building of great navies, with requisite ordnance, created a demand for nickel in ever increasing quantities. From 1914 to 1918 this increasing demand reached its peak. Every source of nickel was tapped. The whole effort of the nickel industry was focused on getting out enough nickel to satisfy the demand. With the end of the war, the bulging market for nickel vanished. There were two possibilities available to the nickel producers to meet this serious change: economies in production, and the development of more diversified industrial uses for nickel and its alloys.

Europe, occupied in stanching the wounds of war, could not immediately enter upon an era of industrial development. The immediate market was America. With the pressure for production removed, economies were introduced, resulting in substantial lowering of production costs. The products were improved in quality and new ones suitable for new industrial uses were brought out. The building of rolling mills especially designed for the rolling of nickel and Monel Metal made these products, with superior strength, uniformity, appearance, and corrosion-resistance, available in quantity.

Information on all nickel-bearing products was carried to industrial engineers. Service and cooperation were offered. The war had stimulated unprecedented thought and research, engineers were looking for better materials, and new products were eagerly investigated. A foundation was carefully laid upon which substantial commercial activity was built. This method, used in both the ferrous and non-ferrous fields of opportunity, proved practical and effective.

In short, through active effort of the nickel companies, with the assistance and cooperation of the metal industries generally, peacetime uses of nickel have been increased and multiplied, with a resultant recovery in the nickel market.

Manufacturing policies today include serious consideration of the supply of raw materials for years ahead. There is not only the question whether this or that material will build a better machine, but also whether there is plenty of that material readily available. In the case of nickel this question has been answered in the affirmative by Nature's lavish deposits in Canada. There is enough nickel ore, of good quality, in the Ontario mining area alone, to supply the world's needs at the present rate for a century.

The nickel industry thus enters the current industrial era on a sound footing. It is well equipped in resources and has high quality products to meet an ever increasing demand. The future years are full of promise.

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